Building Research Establishment Digest

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Low-rise buildings on shrinkable clay soils: Part 2

Foundations for firm shrinkable clays

Volume changes in clay soils brought about by seasonal changes in soil moisture content, and by the removal of soil moisture by deeply rooted vegetation, have caused widespread damage to low-rise buildings, especially following periods of low rainfall. Whether or not substantial shrinkage will occur on any given site is difficult to predict since it depends not only on the soil type, but also on many other factors. Of these the local groundwater condition, which can vary enormously over short distances, is probably the most important. There are considerable differences in the performance of buildings with similar foundations on shrinkable clays. These differences depend largely on whether buildings are sited on open ground, away from the influence of deeper-rooted vegetation (trees, hedges and large bushes), or whether they are sited within the zones affected by growth of such vegetation. Accordingly, these two aspects are discussed separately.

Building on 'open' ground

For more than 25 years the Building Research Establishment has recommended a minimum foundation depth of 0.9 m in order to eliminate significant seasonal ground movements. The value of 0.9 m was selected to cater for movement in the worst types of clay soil during severe droughts. Even during the most severe drought of 1976 there appear to have been very few proven cases of damage to buildings founded at this depth in open ground.

The traditional strip foundation, which is the most common foundation in the UK, may not be economic when placed at depths of 0.9 m or more, and so the narrow strip (trench fill) foundation has gained general acceptance for the 'open' shrinkable clay site.

As protection against the possibility that trees subsequently planted close to new buildings may eventually produce damaging ground movements, or where local ground conditions dictate foundation depths in excess of 0.9 m, the bored pile foundation described later will be most suitable. Pile lengths of up to about 4.5 m are generally satisfactory depending on soil conditions and structural loadings. For large developments, and given favourable ground conditions, these foundations can be as economic as narrow strip foundations. Unless ground beams are cast in exceptionally dry conditions there is no need to allow for large uplift forces on the beams, and floors need not be suspended.

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Buildings sited near major vegetation

The problem of volume changes in clay soil due to the drying action of tree roots is still not appreciated by many builders, engineers, planners and landscape architects. The Building Research Establishment has long warned of the possibility of damage occurring to buildings with foundations which have not been designed to withstand the effects of the roots of nearby large vegetation. Numerous case studies have indicated that there is a risk of some damage once the height of a tree exceeds its distance from a building. The risk appears to be greater when the trees are in groups or rows. Studies have also shown that damage can be caused by most of the common species of tree founded in the UK and also that large shrubs adjacent to buildings can occasionally cause damage. It is difficult to predict with certainty whether damage will occur in any given situation since so many factors are involved which relate both to the building and the ground conditions. Any site investigation for buildings on shrinkable clay with trees present should determine the spread of roots by examination in trial pits.

An assessment of the potential shrinkage of the clay and of the local hydrological conditions should help to identify sites where tree roots may present problems to buildings on shallow foundations.

Buildings can be safely sited close to trees, and vice versa, on clay soil of very high shrinkage potential provided adequate foundations are used. It is necessary to take the foundations below the existing or probable zone of desiccation, or root growth as determined by investigation. Since for large trees of high moisture consumption, especially in periods of very dry weather, these zones can extend to depths of as much as 5 m, the best technical solution appears to be the bored pile foundation.

There has recently been an increasing tendency among builders to construct very deep narrow strip foundations when building close to trees: strip foundation depths of 3 m and more are not uncommon. Three factors make this trend undesirable: the deep strip will, except in small schemes, almost certainly be more expensive than the bored pile solution; instability of the trench sides can lead to serious construction difficulties; there is a danger of horizontal foundation movement when large vertical areas of concrete are subjected to differential lateral pressures resulting from either shrinking or swelling of clay. Piled foundations should not be susceptible to any such lateral pressures.

An additional potentially damaging situation is where trees or hedges have been cut down prior to building. The subsequent long-term swelling of the zone of clay, desiccated by the roots, as moisture slowly returns to the ground, can be substantial. The rate at which the ground recovers is very difficult to predict and if there is any doubt that recovery is complete then bored pile foundations and suspended floors should be used.

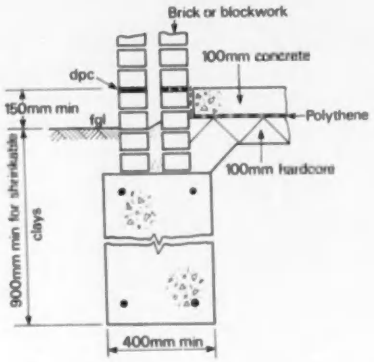

Fig 1 Narrow strip foundation for shrinkable clays

Foundations on the 'open' clay site

The use of the narrow strip (or 'trench fill') foundation for houses on clay sites was first proposed in 1947. At that time the need was accepted to take foundations to a depth of 0.9 m in order to avoid excessive movements by the seasonal swelling and shrinkage of clays. It was appreciated that the minimum width of about 500 mm required for laying bricks in the 0.9 m deep trench resulted in bearing pressures which were uneconomically low for stiff clays. By adopting a narrow trench, say 400 mm wide, which could be cut by a mechanical excavator and filled with mass concrete (Fig 1), a bearing pressure of about 125 kN/m² would result. This pressure would not be excessive for stiff clays and the trench could be cut to a depth of 0.9 m or more without support. The narrow strip foundation considerably reduced the volume of excavation and while there was a 50 per cent increase in the quantity of concrete for a strip 0.9 m deep, this was cheaper in 1 : 9 concrete than the brickwork it replaced. There were also useful savings in unskilled labour in trimming the trench sides and bottom and in the skilled labour for foundation brickwork.

In order to achieve the economies inherent in this design, the narrow strip foundation requires a standard of accuracy in setting out and construction somewhat higher than that needed for the traditional strip. Accuracy in line is required to avoid the brick footing courses projecting over the edge of the narrow concrete strip, and accuracy in level is needed since there are usually no more than four or five courses of brickwork between the top of the foundation and the dpc. Three of these courses must be built true to line

and level to achieve the required architectural appearance of the external brickwork. Care is also needed in positioning the services which pass through the footings, since their location cannot be easily adjusted once they are cast into the foundation concrete. In the case of traditional strip foundations, the services are located within the footing brickwork.

Nominal reinforcement may readily be inserted in narrow strip foundations. Modern buildings are frequently brittle because of the use of strong mortars and such reinforcement will provide added assurance against the possibility of foundation movement causing minor damage. This is particularly relevant where there is some local variability in soil composition and strength that might cause differential settlement within a foundation.

Cases have been reported of damage to narrow strip foundation in desiccated clay following a period of low rainfall during construction. Heavy rain falling before the superstructure loads had been applied to the foundations caused the clay to swell and heave, lifting and cracking the foundations. Swift construction of the superstructure is desirable in these circumstances.

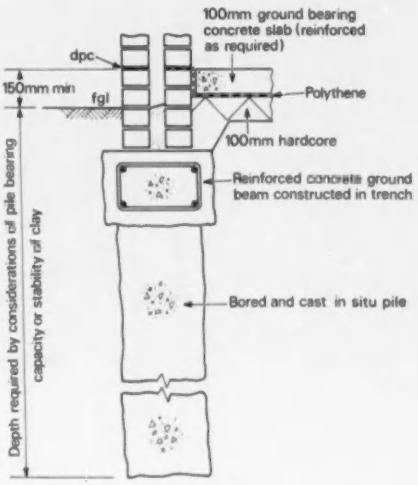
100mm ground bearing concrete slab (reinforced as required)
dpc
150mm min
fgl
Polythene
100mm hardcore
Reinforced concrete ground beam constructed in trench
Bored and cast in situ pile
Depth required by considerations of pile bearing capacity or stability of clay

Fig 2 Design of bored pile foundation for houses sited on loose fill, soft compressible soils and open heavy clay

Pile foundations for clay sites with trees

In cohesive soils above the water table, piles can be bored by mechanical auger. Reinforced ground beams supporting the load-bearing walls are usually cast in situ in trenches cut below ground level to avoid formwork. The resulting foundation (Fig 2) should cost less than strip footings taken to the required depth. Where ground conditions are unfavourable to mechanical auger boring, (such as in glacial clays containing boulders and clays containing hard, claystone layers or pockets of dense sand) cased percussion drilling or driven and cast-in-situ piling is necessary, with substantially increased costs.

Small diameter, driven precast, shell piles, as shown in Fig 3, can also be used on level sites of uniform clay soil. However, light piling rigs for small, driven piles are not widely available and bringing larger and heavier plant to site adds to the overall cost of piling work. On speculative housing sites where the builder does not want to commit himself to constructing all the foundations in advance of selling the houses, several visits by the specialist piling contractor may be necessary.

For buildings on sites where large trees and hedges have been removed, the upper part of the pile shaft should be sleeved in polythene sheeting, or pvc or cardboard tubes, to reduce uplift forces from the swelling clay. Tension reinforcement over the full length of the pile is necessary to deal with any residual uplift forces (see Fig 4). The pile shaft below the sleeved zone should be of sufficient length to provide the required frictional resistance to any residual uplift force. As an alternative to sleeving the upper part of the pile, the pile may be lengthened to provide the necessary frictional resistance against uplift. Adequate tensile reinforcement must, of course, be included to resist the full uplift force.

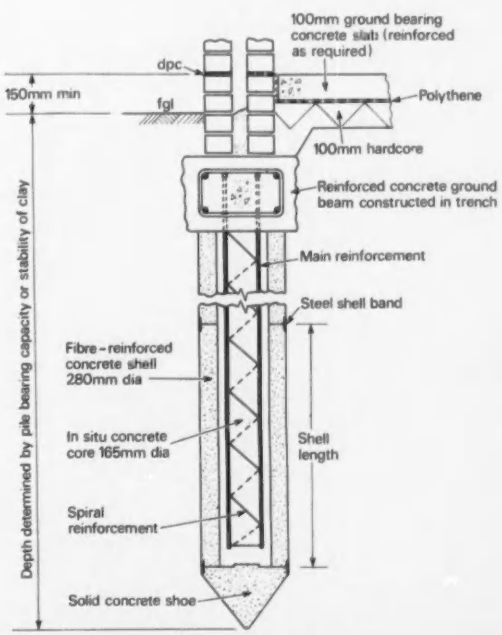

Fig 3 Design of driven, mini-shell pile foundation for houses sited on loose fill, soft compressible soils and shrinkable clays
(Courtesy of West's Piling and Construction Co Ltd)

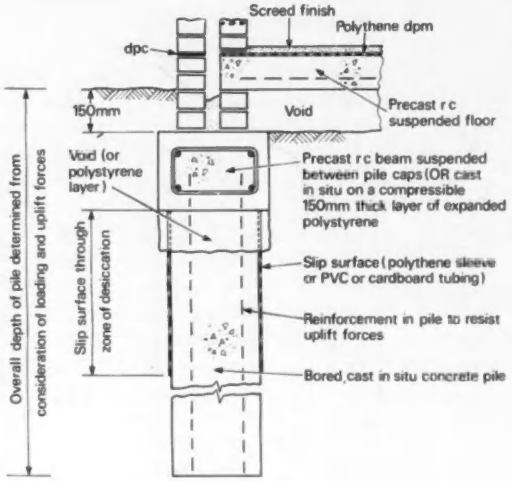
Screed finish
Polythene dpm
dpc
150mm
Void
Precast r c suspended floor
Void (or polystyrene layer)
Precast r c beam suspended between pile caps (OR cast in situ on a compressible 150mm thick layer of expanded polystyrene
Slip surface (polythene sleeve or PVC or cardboard tubing)
Reinforcement in pile to resist uplift forces
Bored cast in situ concrete pile
Overall depth of pile determined from consideration of loading and uplift forces
Slip surface through zone of desiccation

Fig 4 Design of bored pile foundation to resist uplift in swelling clay condition

In order to accommodate swelling pressures on the underside of the capping beams they may be cast in situ on to a layer of compressible material eg polystyrene. Alternatively, pre-cast, suspended, beams may be used, in which case the void beneath the beam accommodates any vertical ground swell. Ground floor slabs should also be suspended. Either pre-cast concrete units or timber floors, with void ventilation, are suitable. A recently developed, alternative method of providing a void beneath in-situ ground beams is to cast directly on to a honeycomb fibre board of sufficient compressive strength when dry to support the weight of concrete and steel. The fibre board is designed to deteriorate structurally as it moistens, producing a moist layer of degraded board which can compress when ground heave occurs so that upward forces are not transmitted to the beams.

Whilst most piling for low-rise foundations is carried out by piling contractors, some builders have successfully developed their own light, mobile lorry or tractor-mounted auger rigs. In favourable conditions some 80 piles per day can be drilled with these machines (ie the foundations for approximately four to eight houses, depending on type). However, the installation of piled foundations requires considerable care and experienced supervision since defective workmanship in piles or ground beams can result in severe damage to the superstructure.

A comparison of foundation costs

The construction of terraced houses in a new town in Essex was costed to compare two types of foundation in firm/stiff shrinkable clay, on an 'open' site, well away from the influence of major vegetation. The average cost of narrow strip foundations for 25 houses was compared with the average for 25 houses with bored-pile and beam foundations. The strip foundations were taken to a depth of 1 m, while the piling was to a depth of about 4 m. Reinforced ground beams between piles were cast in situ on a layer of building paper over ash. In the table, the costs of these foundations per house are shown relative to the costs of piled foundations (100), to remove the effects of inflation.

It was not possible to construct traditional strip foundations on this site but, for comparison, the cost of a 1 m deep, traditional strip foundation has been included, based on labour productivity and material costs for the site.

Estimated foundation costs
(Average of 25 terraced houses)

	Narrow strip (trench fill)	Bored pile and beam	Deep traditional strip
Total relative foundation costs	102	100	127

In all cases, costs included site stripping, setting out, excavation and spoil removal, concrete, reinforcement, hardcore, concrete slabs and brickwork to dpc level. An additional cost was included for design and supervision of the piling. Overhead costs and profit were not included.

The excavation plant consisted of a trenching machine with a 0.38 m bucket and a 0.3 m dia mechanical auger mounted on a tractor.

The main factors, apart from the designer's specification, which affect relative costs are:

(a) Properties of the soil.

(b) Design of foundations and shape of the building. Pile and beam foundations are particularly advantageous when lightweight superstructure materials are used, the smaller loads permitting fewer or smaller piles and cheaper beams. When buildings have large window openings on the ground floor, piling is particularly suitable as loads between openings can be carried on single piles whereas the dimensions of continuous footings are normally not varied around a building.

(c) Method of construction and size of contract.

(d) Local prices of materials.

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